LONDON-WEST MIDLANDS ENVIRONMENTAL STATEMENT

Volume 5 | Technical Appendices

CFA17 | Offchurch and Cubbington

Offchurch to Cubbington river modelling report (WR-004-010)

Water resources

November 2013

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1 Overarching modelling approach

1.1 Introduction

1.1.1 The Country North section of the Proposed Scheme crosses numerous watercourses with the potential for affecting flood risk. Hydraulic modelling has been carried out to assess the current (baseline) river flood risks at each of these watercourse crossings and the potential impacts of the proposed culvert and viaduct structures. Therefore, the primary objective of this assessment was to assess the impact of the Proposed Scheme on river flood risk.

1.1.2 The outcome of this assessment has aided the design team to determine the type and dimension of structures required to convey the watercourse flows; and mitigation measures for any remaining residual flood risk.

1.1.3 A hydraulic modelling assessment of flood risk was undertaken for watercourses affected by the Country North section. These watercourses were grouped into seven CFA in the Country North section. Existing hydraulic models of the watercourses have been utilised where available and new river hydraulic models were built for the other watercourses. This report describes the hydraulic modelling processes and outcomes of this assessment.

1.1.4 The main conclusions from this modelling report form the basis of the river flood risk in the Flood Risk Assessment for CFA17 (WR-003-017). These conclusions are also reported within the Water Resources and Flood Risk Assessment section of Volume 2 of the Environmental Statement (ES).

1.2 Hydrology

1.2.1 Watercourses with existing hydraulic models adopted standard Flood Estimation Handbook (FEH) techniques for hydrological assessment. The hydrology of these models was reviewed for suitability for use in this study.

1.2.2 For the watercourses with no existing hydraulic models, hydrological assessments were undertaken in this study to determine the design flows.

1.2.3 The hydrological catchments of the watercourses to each of the route crossings have been determined from the FEH CD-ROM[1] for watercourses represented in this data set. For the purposes of this assessment it was assumed that catchment boundaries as represented in the FEH CD-ROM were correct, therefore a detailed assessment of catchment boundaries has not been completed. The catchment descriptors have also been taken from the FEH CD-ROM and updated for urban expansion to 2012, using Equation 6.8 in Volume 5 of the FEH[2]. This is a standard industry technique.

1.2.4 River flows at watercourse crossing locations were determined using the Revitalised Flood Hydrograph (ReFH) method[3] in the first instance. In line with the current Environment Agency flood estimation guidance, the ReFH method is deemed acceptable for the majority of catchments along the route and is the most time

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[1] Centre for Ecology and Hydrology (2009) *FEH CD-ROM Version 3*, ©NERC (CEH).
[2] Centre for Ecology & Hydrology (CEH). 1999. *Flood Estimation Handbook – Volume 5: Catchment Descriptors (1999)*.
[3] Centre for Ecology & Hydrology (CEH). 2007. *The revitalised FSR/FEH rainfall-runoff method: Supplementary Report No. 1 (2007)*.

efficient method for determining flows for studies where numerous flows are required.

1.2.5 The ReFH method is not considered acceptable for all catchments, in this case those classed as highly permeable. Based on the FEH CD-ROM catchment descriptors, a number of the catchments are classed as highly permeable and hence in line with current Environment Agency guidelines[4], an alternative method was required. Therefore at these locations, the FEH Statistical method, with a permeable adjustment was utilised, as recommended in the guidelines.

1.2.6 Not all watercourses that will be crossed by the route were represented in the FEH CD-ROM; therefore, the catchment boundaries could not be determined using the FEH CD-ROM. In these instances, catchment boundaries have been determined through the use of topographic data from Light Detection and Ranging (LiDAR) data and Ordnance Survey (OS) mapping at a 1:10,000 scale. At locations of uncertainty, a slightly larger catchment has been assumed as a conservative approach. Flows for these catchments were determined through a conservative area scaling method. Based on the flows estimated for FEH CD-ROM represented catchments, a maximum flow rate of 1.4 and 2.6m^3/s per km^2 was calculated for the 1 in 100 (1%) annual probability and 1 in 1000 (0.1%) annual probability events respectively. These flow rates, along with a 10% error allowance (to prevent an underestimation of flow), were used as scaling factors.

1.2.7 The estimated peak flows were used as either a constant inflow boundary or as a full hydrograph. The peak flows estimated using this method were for the 1 in 20 (5%) annual probability, 1 in 100 (1%) annual probability and 1 in 1000 (0.1%) annual probability events. Flow during the 1 in 100 (1%) annual probability event with an allowance for climate change was estimated by factoring the 1 in 100 (1%) annual probability flow by 20% (refer to 'Section 3 – Design Criteria' of the Flood Risk Assessment WR-003-017).

1.3 Hydraulics

General approach

1.3.1 The hydraulic modelling approach depended on the characteristics of the particular watercourse and floodplain hydraulics. The approach of either steady or unsteady modelling was based on whether there were rapid increases or decreases in flows, flood storage areas or structure impacts on channel/floodplain flows. The modelling approach also varied based on requirements of assessing the flow routes either in one-dimension or two-dimension.

1.3.2 The modelling approach adopted in this study was as follows:

- if the modelling was utilised for sizing the culvert crossings on watercourses with no significant floodplain attenuation or structure impacts, steady state one dimensional modelling was adopted;
- if there was significant floodplain attenuation and/or structure impacts on channel/floodplain flows, one dimensional hydrodynamic modelling was

[4] Environment Agency (2012) *Flood estimation guidelines (197_08)*.

adopted; and

- if there was significant floodplain attenuation and/or structure impacts on channel/floodplain flows, and a requirement for accurately defining the flood extents, two dimensional or a one dimensional-two dimensional combination modelling was adopted.

1.3.3 Existing models were first reviewed to assess their suitability for use. If more recent data such as topography was available the models were updated accordingly. If the level of detail within the model, such as the floodplain, was not appropriate, the model was upgraded accordingly.

1.3.4 The hydraulic modelling approach was based on the Environment Agency guidelines[5].

1.3.5 Two industry standard hydraulic modelling software packages have been utilised as part of this assessment: ISIS version 3.6 and TUFLOW version 2012.

Hierarchical approach

1.3.6 Any existing Environment Agency models for the watercourses were used to assess the current and future flood risk impacts of any watercourses crossing the route.

1.3.7 For watercourses without existing hydraulic models, the modelling process was carried out in a phased manner to assess the baseline flood risk and impacts of the Proposed Scheme. In the first phase, the watercourses with culverted crossings were modelled as simple unsteady one dimensional hydraulic models, to assess the adequacy of culverts in conveying flood flows. In the second phase, watercourses for both culverted and viaduct crossings were modelled as two dimensional hydrodynamic models to define the flood extents and assess the impacts of the various structures on flood risk. The two dimensional model outputs were then used to inform the design team of flood risk.

1.3.8 All the models were run for the 1 in 100 (1%) annual probability with an allowance for climate change and 1 in 1000 (0.1%) annual probability events. Some of the models were run for the 1 in 20 (5%) annual probability event where the potential impacts on flood risk could affect vulnerable receptors.

1.3.9 The 1 in 100 (1%) annual probability with an allowance for climate change peak water levels for the baseline and Proposed Scheme were compared upstream and downstream of the crossing to assess the impact on flood risk. The scheme impact on flood risk and the width of the 1 in 100 (1%) annual probability with an allowance for climate change flood extents, defined the type of structure to be used at the crossings i.e. culvert or viaduct and the dimensions of culverts/viaducts. The structure type was selected based on its adequacy in conveying flood flows without significantly affecting flood risk.

1.3.10 The peak water levels for the 1 in 1000 (0.1%) annual probability event confirmed whether the vertical alignment met the design criteria (refer to 'Section 3 – Design Criteria' of the Flood Risk Assessment WR-003-017).

[5] *'Requirements for completing computer river modelling for flood risk assessments – Guidance for developers'* Version 3.0 (August 2009), Environment Agency.

Input data

1.3.11 Existing Environment Agency hydraulic models were used where available, which for this study area was the River Leam model from the Hazard Mapping Study (JBA, 2010)[6]. The channel topography and hydrology used in this model was considered adequate and suitable for the purposes of this study.

1.3.12 The topographic data used was LiDAR data that was flown in 2012, covering the extent of the Proposed Scheme, providing data as fine as up to 0.2m horizontal resolution. This data was used to create digital terrain models (DTM) for use within the hydraulic models. In most cases, the DTM has been resized to a 1m resolution for suitability in the two dimensional models. For watercourses without existing hydraulic models, there were no topographic surveys available and hence river sections and floodplain topography were derived from this DTM.

1.3.13 For existing models, the floodplain topography was updated with this DTM. The channel topography in these models was taken from topographic surveys undertaken previously.

1.3.14 Inflows to the watercourses were taken from the hydrological assessments as discussed in Section 1.2 of this report.

1.3.15 The data for the Proposed Scheme model scenario was taken from the scheme drawings.

One dimension modelling

1.3.16 In the first phase, one dimensional ISIS models were constructed representing a 200m to 300m reach of the watercourse. The purpose of these models was to assess the adequacy of culverted crossings in conveying flows. These models used the LiDAR data to define extended cross sections which included the channel and floodplain topography. The roughness of the channels and floodplains is defined by the Manning's roughness parameter. The Manning's values were based on the particular land use type as observed from aerial photographs. Steady state flows were applied as upstream inflow boundaries and a normal depth boundary was applied at the downstream extent. The normal depth boundary was based on the bed slope of the topography at that location and is considered suitable for the purpose of the modelling.

1.3.17 The Proposed Scheme model included rectangular conduit units to represent the structures at the crossings. There were two types of culverts adopted: a minimum culvert size of 2m by 1.5m and a maximum culvert size of 4m by 2m. The dimensions adopted here represent the flow area of the culvert rather than the full dimensions of the culvert that will need to be larger to accommodate depressed inverts and mammal ledges as appropriate. The lengths of the culverts were based on the width of the route crossings as defined in the post-consultation route.

Two dimension modelling

1.3.18 In the second phase, unsteady state two dimensional TUFLOW models were built to accurately define the flood extents and floodplain attenuation. The two dimensional

[6] JBA on behalf of the Environment Agency. July 2010. *River Leam Hazard Mapping – Final Report*.

models were built on a 5m cell resolution with LiDAR data used to create the DTM, which defined the floodplain and channel topography.

1.3.19 It should be noted that components within a two dimensional TUFLOW model such as SXZ, HX, Z-polygon, Z-Shape polygons, etc., are based on naming conventions as mentioned in the TUFLOW manual[7].

1.3.20 The Manning's roughness values of the channels and floodplains were based on the particular land use type as observed from aerial photographs.

1.3.21 The inflow to each watercourse was applied upstream using a TUFLOW boundary condition polyline layer, linking it to a flow time series within a boundary condition database. The flow type is either constant flow or hydrograph flow, depending on the attenuation within the floodplain. A flow-head (HQ) polyline layer was used for the downstream boundary, based on the slope of the floodplain at that location; which was considered suitable for the scale and level of detail of the modelling. The models have been run at a two second timestep for varying durations.

1.3.22 The Proposed Scheme model was built by adding either culvert or viaduct structures to the baseline model at the watercourse crossings.

1.3.23 Viaduct structures have been modelled by adding the Proposed Scheme embankments as Z-polygon or Z-Shape polygon layers with an opening at the viaduct crossing. The Z-polygon or Z-Shape polygon layers are Geographic Information System (GIS) polygons with elevations. Where piers were modelled, they were represented as Flow Constriction (FC) shape layers. The soffit levels were not added into the model. This was because the 1 in 1000 (0.1%) annual probability modelled peak flood levels, along with sufficient clearance, will form the basis of designing the soffit heights (refer to 'Section 3 – Design Criteria' of the Flood Risk Assessment WR-003-017).

1.3.24 Culvert structures have been modelled by adding a one dimensional network layer representing the extent of the culvert, the length of which was determined by the width of the route at the crossing point (including embankment earthworks and any landscaping). Inverts were defined at the inflow and outflow points of the culvert extracted from the LiDAR DTM for the area. This one dimensional network layer was connected to the two dimensional domain with a SXZ point link, a GIS point used in the modelling software for one dimension two dimension linking. An embankment was modelled across the route as a Z-polygon layer, covering the extent of the upstream floodplain at the route crossing so that all flow was routed through the culvert.

One dimension -two dimension linked modelling

1.3.25 In certain cases where existing one dimensional models were not representing complex channel-floodplain interactions accurately, dynamically linked one dimensional-two dimensional models were constructed. The channel component was represented in one dimensional and the floodplain component in two dimensional. One dimensional-two dimensional models were built using ISIS-TUFLOW.

[7] TUFLOW User Manual, 2010, BMT WBM.

1.3.26 The flows between the one dimensional and two dimensional model components were controlled via a GIS polyline layer (HX layer), the spill levels of which were defined by the channel bank levels or DTM levels.

1.3.27 In the Proposed Scheme scenarios, the viaduct structures were represented as discussed earlier in the two dimensional modelling section (Section 1.3.21 of this report).

Sensitivity assessments

1.3.28 Sensitivity assessments have been undertaken on various parameters of the models to reflect the uncertainties and impacts on modelled flood levels. Assessments have been carried out on inflows and culvert blockages. In the case of viaduct crossings, sensitivity was undertaken on inflows.

1.3.29 Sensitivity on inflows was carried out by varying the 1 in 100 (1%) annual probability with an allowance for climate change and the 1 in 1000 (0.1%) annual probability flows by 20%. This was undertaken for the baseline and Proposed Scheme scenarios, unless stated otherwise.

1.3.30 Sensitivity has also been carried out on Proposed Scheme scenarios with culvert structures by adding 10% blockage. Resulting models have been run for the 1 in 100 (1%) annual probability with an allowance for climate change and the 1 in 1000 (0.1%) annual probability events.

1.4 Assumptions and limitations

Hydrology

1.4.1 The catchment boundaries and catchment descriptors as taken from the FEH CD-ROM are correct and accurately represent the catchments in reality.

1.4.2 For catchments not classed as highly permeable, the ReFH method results in the most accurate estimation of flow at the location of the crossings in comparison to other methods.

1.4.3 The FEH Statistical method with permeable adjustment results in the most accurate estimation of flow at catchments classed as highly permeable.

1.4.4 The area scaling method, results in conservative flow estimates for catchments which are not represented in the FEH CD-ROM (refer to Section 1.2 of this report for detail).

1.4.5 There are no external influences on flow at the location of the crossing, such as significant abstractions or discharges.

1.4.6 A 20% allowance for climate change on peak flow rates has been used for the assessment of river flood risk (refer to 'Section 3 – Design Criteria' of the Flood Risk Assessment WR-003-017).

Hydraulic modelling

1.4.7 Only river flood risk was considered during the hydraulic modelling in this assessment.

1.4.8 For watercourses without existing hydraulic models, the channel geometry was extracted from the LiDAR DTM with the channel width defined by the 5m cell

resolution of the two dimensional model. Therefore, the watercourse geometry is not well defined, the consequence of which is an underestimate of the channel conveyance and hence, an overestimation of the floodplain inundation.

1.4.9 There were certain watercourses with road crossing structures upstream or downstream of a route crossing, causing a significant impact on hydraulics. OS mapping and aerial photography were used to assess the location of the structures. The inverts of any culvert structure were assumed to be the channel bed levels from the LiDAR DTM; and structure widths as the width of the channel.

1.4.10 In the Proposed Scheme in models involving viaducts, the structure was represented by the piers and embankments. The scheme drawings were used to obtain the footprint of the piers and the dimensions incorporated into the model. The soffits of the viaducts were not modelled as the design approach for the structures is to include a suitable clearance between peak flood level and the structure soffit.

2 Modelling at watercourse crossings

2.1 Overview

2.1.1 River modelling undertaken at the various watercourse crossings for CFA17 is summarised in Table 1, along with the modelling methodologies adopted. Figure 1 identifies the location of each of these structures.

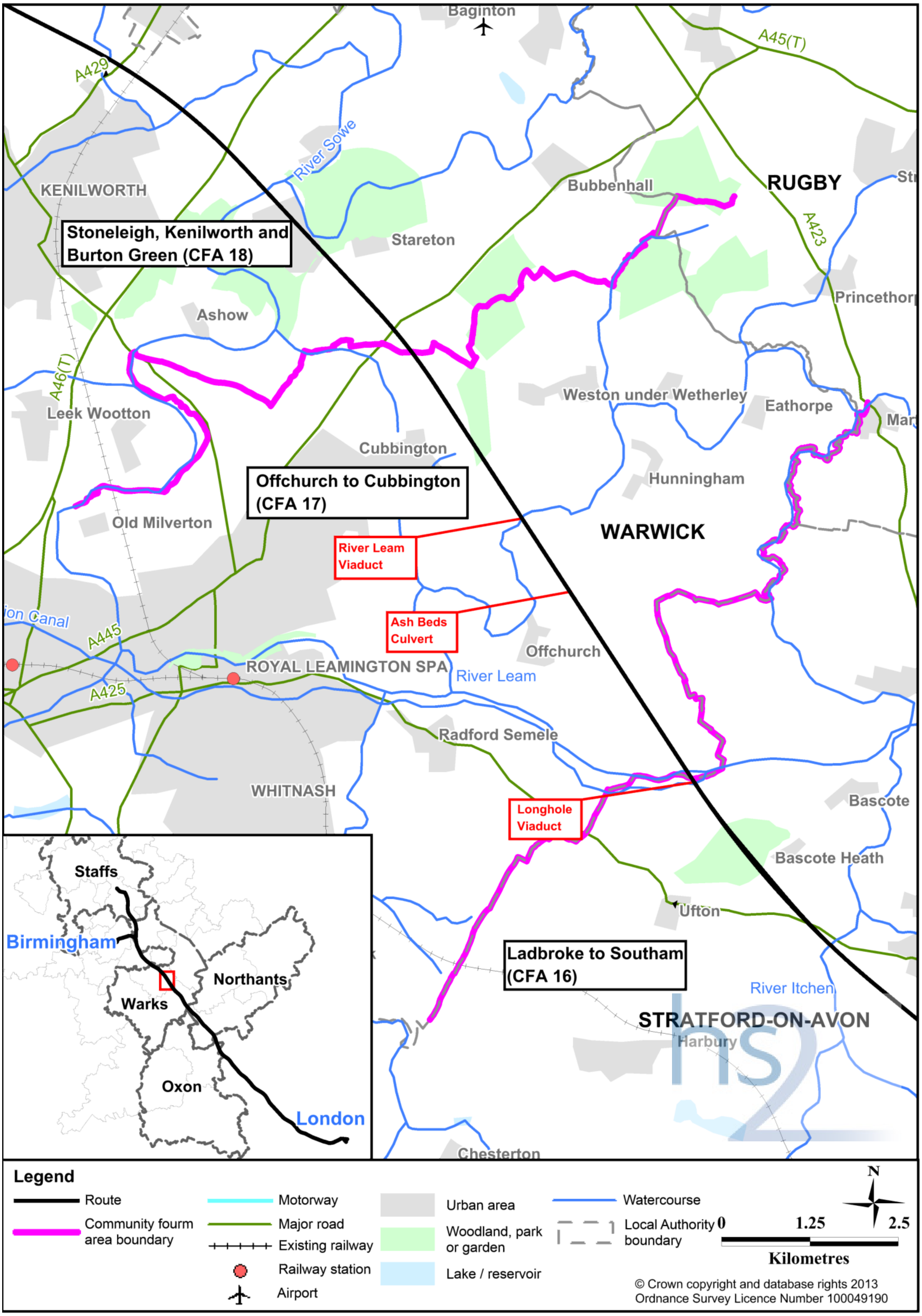
Table 1: River models at watercourse crossings

Crossing name	Watercourse identifier	Watercourse	Hydrology	Hydraulic modelling
Longhole viaduct	SWC-CFA17-001 Map WR-01-028, H6	Ordinary watercourse (tributary of the River Leam)	ReFH	two dimensional hydrodynamic
Ash Beds culvert	SWC-CFA17-004 Map WR-01-028, E5	Ordinary watercourse (tributary of the River Leam)	ReFH	one dimensional steady state
River Leam viaduct	SWC-CFA17-005 Map WR-01-028, D5	Main river (River Leam)	Standard FEH techniques as used in the River Leam Hazard Mapping Study	one dimensional-two dimensional hydrodynamic model as used in the River Leam Hazard Mapping Study

2.1.2 A summary of the modelling for the Ash Beds culvert structure is described in Section 2.2 of this report. The modelling is described in detail for the Longhole viaduct and River Leam viaduct in Section 2.3 and Section 2.4 within this report.

2.1.3 The details of the specific modelling methodologies, hydraulic constraints and any assumptions of each of the watercourse crossings are discussed in the following sections.

Figure 1: Location map



2.2 Culverts

2.2.1 The one dimensional ISIS hydraulic models built for the baseline and Post Scheme scenarios used the general methodologies for one dimensional modelling as discussed in Section 1.3 of this report. The Ash Beds structure adopted here was the maximum culvert size of 4m x 2.5m dimension with 70m length. The impact of the scheme on peak flood levels is summarised in Table 2. The structure dimensions of width (W), height (H) and length (L) in metres is also provided in this table.

2.2.2 Details of the hydrological assessment for this watercourse are provided in Section 3 of this report.

Table 2: Modelled peak levels for culvert crossing

Watercourse identifier	Structure dimensions (WxHxL)	Flood event	Peak flood level		Change in flood level	Length of impact upstream reach[8]
			Baseline	Scheme		
SWC-CFA17-004	4m x 2.5m x 70m	1 in 20 (5%)	60.577mAOD	60.546mAOD	-31mm	12m
		1 in 100 (1%) climate change	60.687mAOD	60.718mAOD	31mm	
		1 in 1000 (0.1%)	60.780mAOD	60.889mAOD	109mm	

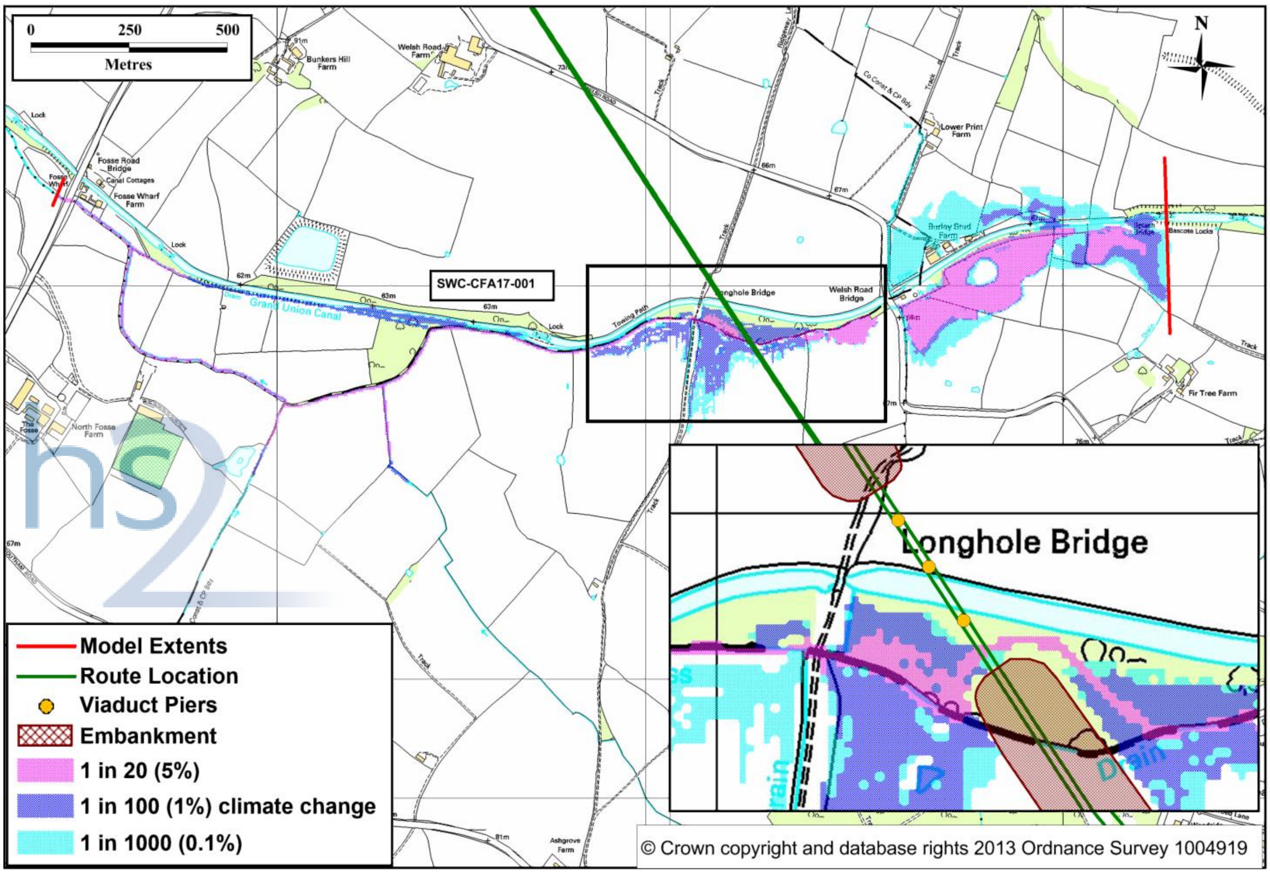
2.2.3 The model results show a localised increase of peak levels of up to 31mm near the structure with increases greater than 10mm limited to within 12m of the watercourse crossing. Therefore, there is no significant increase in flood risk due to the culvert structure.

2.3 Longhole viaduct

2.3.1 This crossing consists of a viaduct structure of 135m width which will cross the ordinary watercourse SWC-CFA17-001 (Volume 5: Map WR-01-028, H6) as shown in Figure 2. The watercourse flows from east of the crossing and continues west within the model extents shown in Figure 2.

[8] Length of reach upstream of the Proposed Scheme along which flood levels during the 1 in 100 (1%) annual probability with an allowance for climate change event are greater than 10mm.

Figure 2: Crossing location plan and flood extents for Longhole viaduct



Hydrology

2.3.2 No existing hydrology was available for this watercourse. The hydrological inflow was calculated using the ReFH method for the drain to the south of the canal. The catchment area was determined from the FEH CD-ROM. Catchment descriptors were extracted from the FEH CD-ROM and updated for urban expansion. The critical storm duration was calculated at the location of the crossing. Flows were then calculated based on these catchment descriptors as no suitable local donor station was identified. A hydrological inflow has not been calculated, nor applied along the Grand Union Canal. Details of the hydrological assessment are provided in Section 0.

Table 3: Hydrology results: model inflows for Longhole viaduct

Watercourse identifier	Environment Agency Flood Zone	1 in 20 (5%) flow	1 in 100 (1%) climate change flow	1 in 1000 (0.1%) flow	Modelled structure
SWC-CFA17-001	3	2.76m^3/s	4.70m^3/s	6.92m^3/s	Viaduct

Hydraulics

2.3.3 No existing hydraulic models were available for this watercourse. A TUFLOW model has been constructed and built with a 5m cell resolution. The topography of the model is based upon 5m resolution LiDAR data. Around the location of the route, more detailed 0.2m resolution LiDAR data has been utilised. A Manning's n value of 0.05 has been used to define the floodplain and a value of 0.03 has been used to define the watercourse. These values have been selected based on a desk-based study.

2.3.4 Watercourses within the modelled extent have been defined using the TUFLOW 'flow constriction' and 'storage reduction factor' functions. These allow for the capacity of the channel to be reduced and not limited to the cell resolution of the model. Approximate bed levels and watercourse widths have been taken from the LiDAR DTM.

2.3.5 The elevation taken from the LiDAR DTM has been used to represent the water level of the Grand Union Canal. Upstream of Welsh Road, the Canal is shown to be at the same elevation as the road, whereas downstream there is a drop in elevation of approximately 1m.

2.3.6 An HQ boundary has been applied to the downstream extent of the model and has been automatically generated by TUFLOW based on an assumed floodplain gradient of 0.003. The gradient has been measured from the LiDAR along the channel bed at this location.

2.3.7 The Proposed Scheme model includes the diverted watercourse and the Proposed Scheme embankment. The viaduct soffit has been assumed sufficiently high as to not impact on the results. Piers were not included in this model. Peak levels were extracted 20m upstream of the crossing.

Table 4: Modelled peak flood levels for Longhole viaduct

Flood event	Peak flood level		Change in flood level
	Baseline	Scheme	
1 in 20 (5%)	64.163mAOD	64.163mAOD	0mm
1 in 100 (1%) climate change	64.437mAOD	64.476mAOD	39mm
1 in 1000 (0.1%)	64.470mAOD	64.604mAOD	134mm

2.3.8 Hydraulic constraints:

- Welsh Road Bridge is located approximately 400m upstream of the crossing. The road is raised as it passes over the Grand Union Canal and the drain, and acts as an embankment, retaining out of bank floodwaters behind it. The crest level of the road has been extracted from the LiDAR DTM and enforced in the model. Aerial photography shows that the Grand Union Canal is controlled by a lock at this location, with differing water levels upstream and downstream of the structure. The differing elevations have been represented in the model; however the lock is not specifically represented. The drain is culverted beneath the road embankment and has been modelled in one dimension with the width of the structure equal to the width of the watercourse. The soffit level was estimated by calculating the depth between the crest of the road embankment and the bed level of the drain, minus the clearance required above the flood levels.

- Longhole Bridge is located approximately 50m downstream of the crossing. The track is raised as it passes over both the Grand Union Canal and the drain. The crest level of the road has been extracted from the LiDAR DTM and enforced in the model. The details of the hydraulic structures on the Grand Union Canal and drain are unknown and have been crudely represented by carving the watercourse through the embankment, such that the structures

have no soffit or deck level. The model results currently show some retention of floodwaters behind this embankment.

2.3.9 The baseline floodplain width at the crossing is 138m for the 1 in 100 (1%) annual probability with an allowance for climate change event. The cross section of the watercourse with baseline flood levels upstream of the crossing is shown in Figure 3. The impact of the Proposed Scheme on modelled peak levels is summarised in Table 4. The baseline and Proposed Scheme peak velocity contours are shown in Figure 4.

Figure 3: Cross section and flood levels at crossing of Longhole viaduct

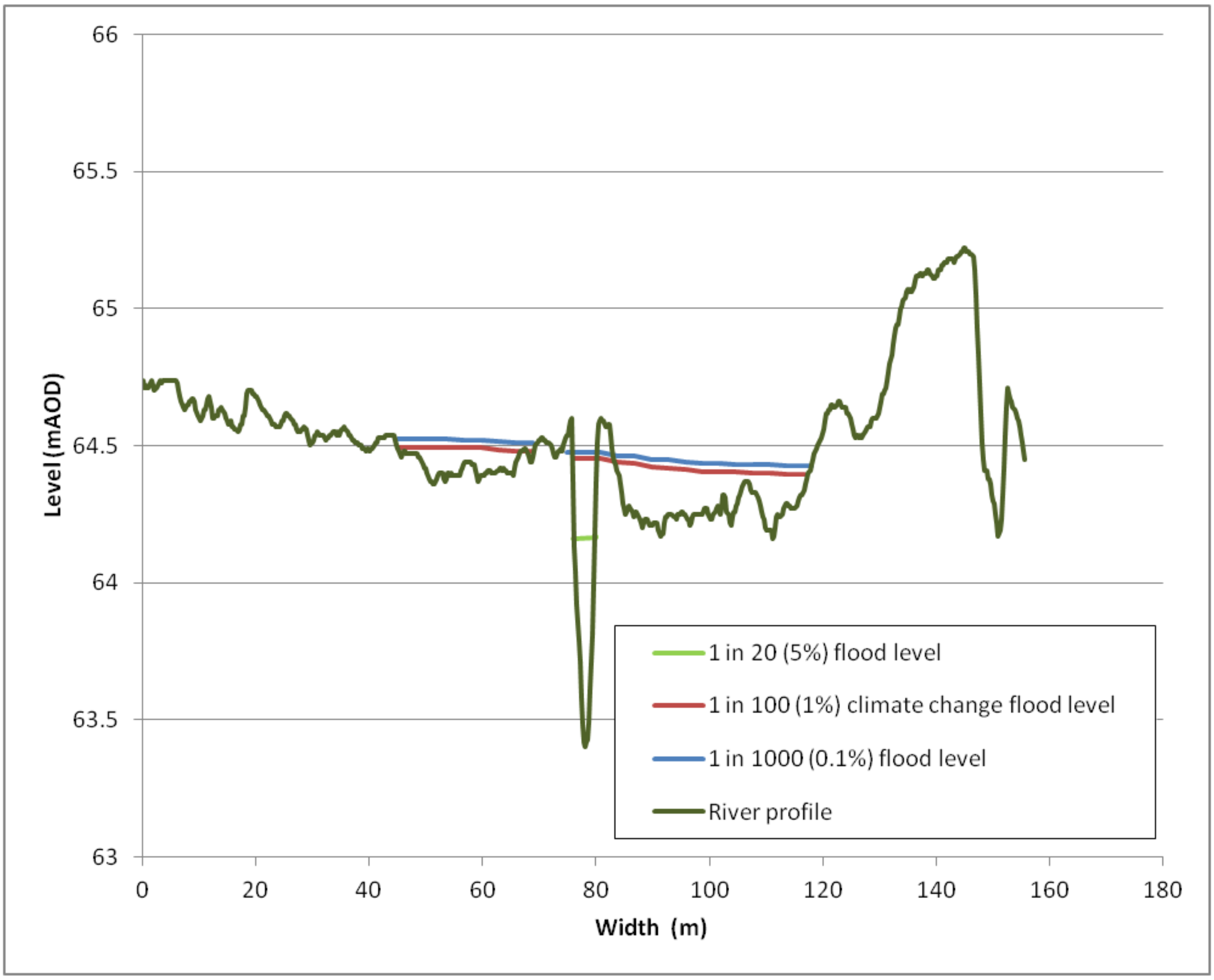
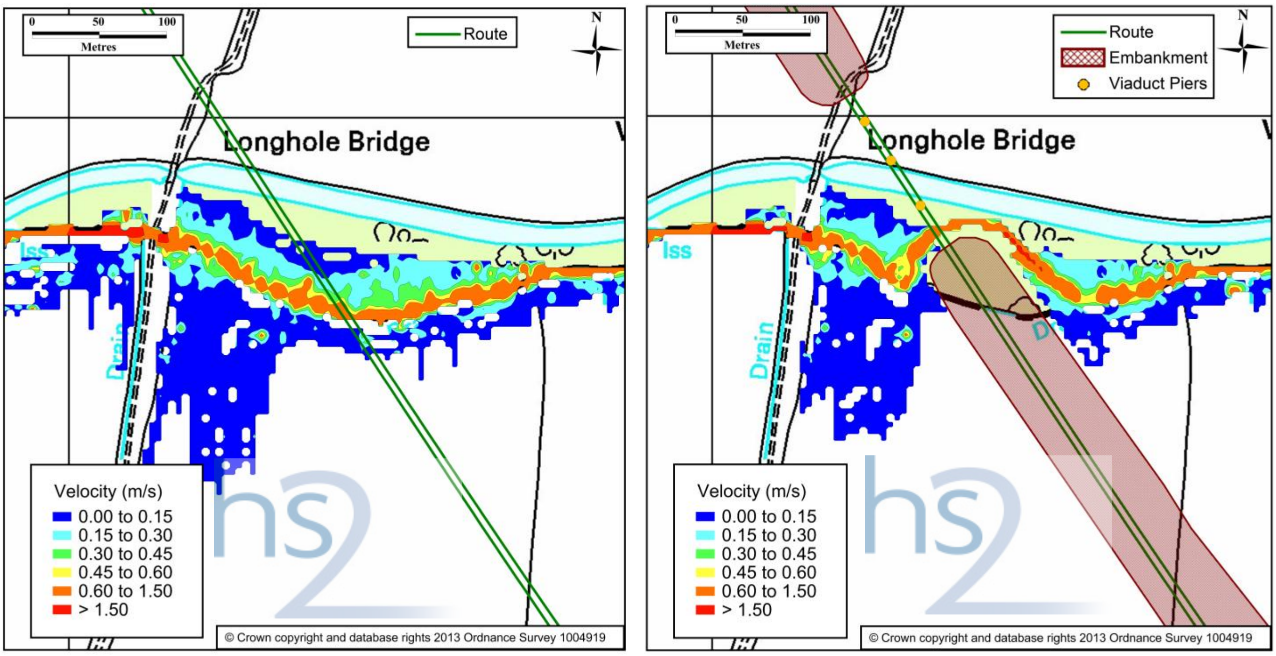


Figure 4: Peak velocity contours for 1 in 100 (%) climate change event for Longhole viaduct



Baseline Proposed Scheme

Sensitivity assessment

2.3.10 Sensitivity assessment was carried out on inflows for the 1 in 100 (1%) annual probability with an allowance for climate change event in the baseline model. A 20% increase in flows caused up to 10mm increase in channel peak levels and no change in floodplain peak levels. A 20% decrease in flow caused up to 30mm decrease in channel peak levels and 10mm decrease in floodplain peak levels.

2.3.11 The increase in flows resulted in increases in flood extent of 47% to the west of Welsh Road Bridge which will affect some additional receptors such as buildings. However, the Proposed Scheme has been shown to have impacts within 72m upstream of the crossing which is east of Welsh Road Bridge. Since, the change in flood extent is outside the zone of impact; the Proposed Scheme will not affect the flood risk at this particular location.

Conclusions

2.3.12 The Proposed Scheme showed up to a 39mm rise in peak levels for the 1 in 100 (1%) annual probability with an allowance for climate change event. The increase of peak levels of greater than 10mm was limited to a 90m reach upstream of the crossing, along which there were no other receptors other than agricultural land.

2.3.13 A replacement flood storage area was identified which provided a like for like storage volume to mitigate the increase in flood risk.

2.3.14 There are localised increases in velocity near the crossing of up to 0.45m/s with minimal increases elsewhere. There is a change in the pattern of the Proposed Scheme velocity contours due to the channel diversion.

2.4 River Leam viaduct

2.4.1 This crossing consists of a viaduct structure of 135m width which will cross the ordinary watercourse SWC-CFA17-005 (Volume 5: Map WR-01-028, D5) as shown in Figure 5. The watercourse flows from north east of the crossing and continues south west within the model extents shown in Figure 5.

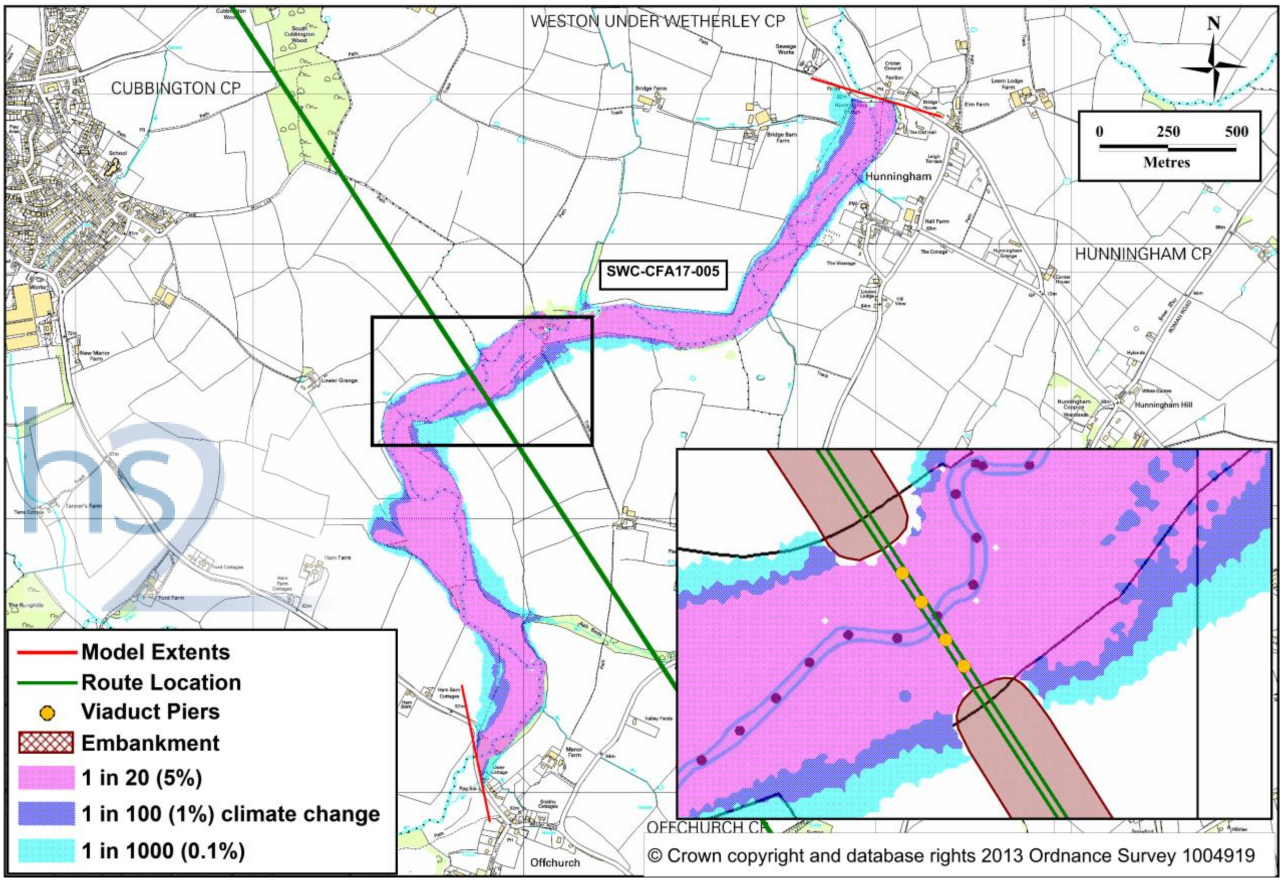
Hydrology

2.4.2 The inflows used in the hydraulic model have been derived as part of the River Leam Hazard Mapping Study[6]. Ratings were developed for local gauges on the River Leam and used the annual maxima (AMAX) data in the calculation of the median annual flood (QMED). The FEH Statistical growth curve is based on an area weighting of the growth curves at Eathorpe and Leamington Princes Drive Weir. The hydrology supplied with the model adopted standard FEH techniques and was retained for this study.

Table 5: Hydrology results: model inflows for River Leam

Watercourse identifier	Environment Agency Flood Zone	1 in 100 (1%) climate change flow	1 in 1000 (0.1%) flow	Modelled structure
SWC-CFA17-005	3	145.97 m^3/s	244.05 m^3/s	Viaduct

Figure 5: Crossing location plan and flood extents for River Leam viaduct



Hydraulics

2.4.3 The ISIS-TUFLOW (one dimensional-two dimensional) model constructed as part of the River Leam Hazard Mapping Study[6] was made available for this study. The reach of the model near the crossing was built in one dimensional only with extended cross sections representing both the channel and floodplain. However, the extended cross sections only crudely represented the floodplain. Therefore, this section of the model was truncated to the area of interest and a two dimensional TUFLOW domain constructed with a 6m cell resolution.

2.4.4 A Manning's n value of 0.05 has been used to define the floodplain. The roughness values of the watercourses have been retained from the original hydraulic model. A value of 0.042 has been selected based on the approach discussed in the River Leam Hazard Mapping Study[6].

2.4.5 A head-time boundary has been used as the downstream condition. The boundary has been generated by extracting results from the original Leam model for each flood event.

2.4.6 The Proposed Scheme model included the Proposed Scheme embankment, assuming the soffit of the viaduct is sufficiently high so as not to impact on the results.

2.4.7 The baseline floodplain width at the crossing is 148m for the 1 in 100 (1%) annual probability with an allowance for climate change event. The cross section of the watercourse with baseline flood levels upstream of the crossing is shown in Figure 6. The impact of the Proposed Scheme on modelled peak levels is summarised in Table 6. The baseline peak velocity contours and Proposed Scheme impact on velocities are shown in Figure 7.

Table 6: Modelled peak flood levels for River Leam viaduct

Flood event	**Peak flood level (mAOD)**		**Change in flood level**
	Baseline	**Scheme**	
1 in 100 (1%) climate change	56.060mAOD	56.073mAOD	13mm
1 in 1000 (0.1%)	56.705mAOD	56.732mAOD	27mm

Figure 6: Cross section and flood levels for River Leam

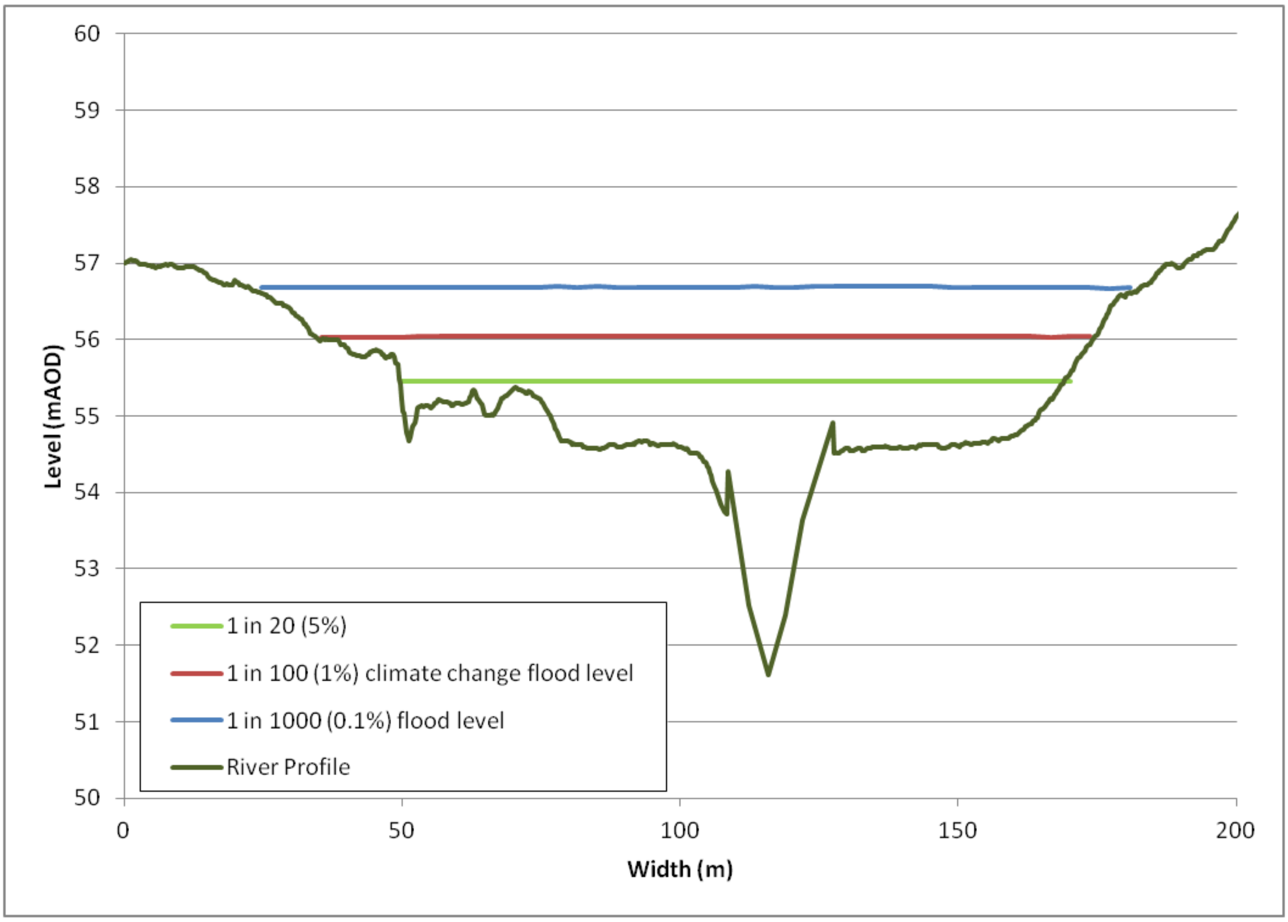
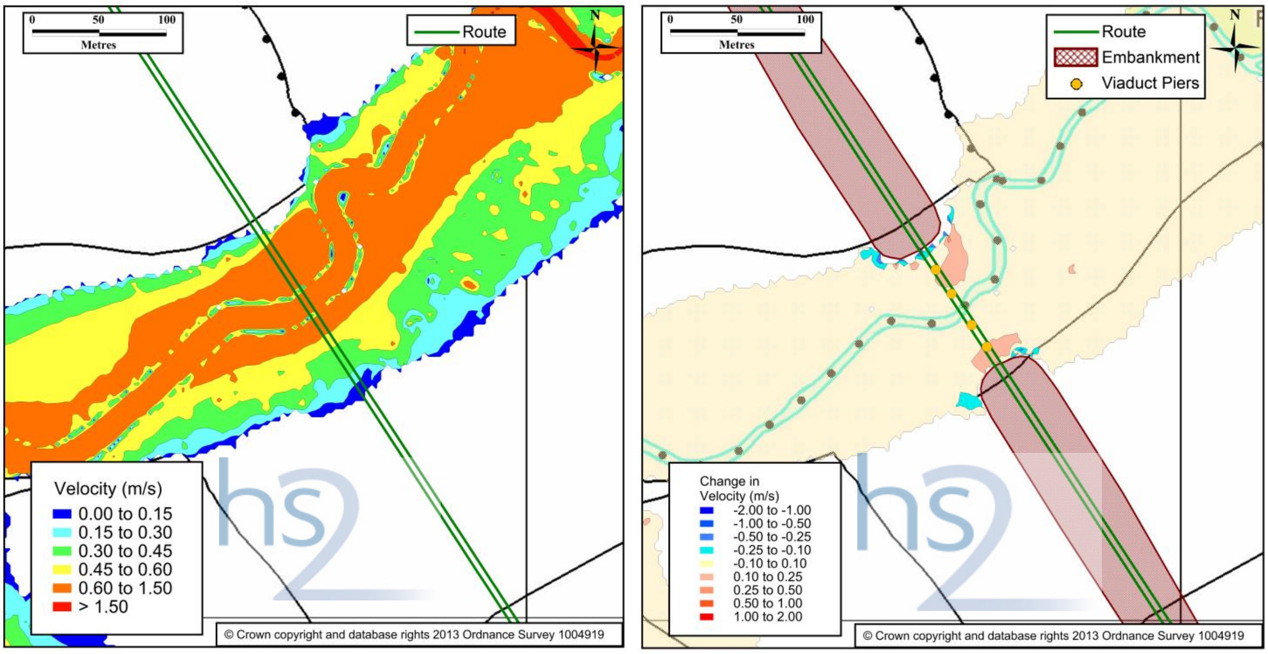


Figure 7: Peak velocity contours and Proposed Scheme impact on velocities for 1 in 100 (1%) climate change event for River Leam viaduct



Sensitivity assessment

2.4.8 Sensitivity assessment was carried out on inflows for the 1 in 100 (1%) annual probability with an allowance for climate change event on the baseline model.

2.4.9 A 20% increase in flows caused up to 220mm increase in both channel peak levels and floodplain peak levels. A 20% decrease in flow caused up to 240mm decrease in channel peak levels and 230mm decrease in floodplain peak levels.

2.4.10 The peak levels with the sensitivity allowance are still well below the soffit level, providing the necessary clearance of 600mm.

2.4.11 The increase in flows caused up to a 7% increase in flood extent with maximum increases downstream of the crossing. There are no additional receptors affected other than agricultural land near the vicinity of these changes. Therefore, the Proposed Scheme flood risk impact still remains valid.

Conclusions

2.4.12 The Proposed Scheme resulted in an increase in peak water level of 13mm for the 1 in 100 (1%) annual probability with an allowance for climate change event. The length of reach with greater than 10mm increase in peak levels was limited to 181m, along which there are no other receptors other than agricultural land.

2.4.13 There is a localised increase in velocity of 0.15m/s at the crossing with minimal changes elsewhere.

2.4.14 A replacement flood storage area was identified which provided a like for like storage volume to mitigate the increase of flood risk.

3 FEH proformas

3.1 Overview

3.1.1 This section provides the FEH proformas for the hydrological calculations of the various watercourses for which there were no existing hydrology available.

3.1.2 The FEH proformas are based on the Environment Agency supporting document to the flood estimation guidelines[4].

3.1.3 The FEH proformas provided here cover watercourse SWC-CFA17-001 at crossing of Longhole viaduct and watercourse SWC-CFA17-004 at the crossing of Ash Beds culvert.

3.1.4 Following review, flows for the crossing on the River Leam have been adopted from the River Leam Hazard Mapping Study[6]. The relevant FEH proformas are provided within this Hazard Mapping study[6] and are not reproduced within this report.

3.2 Longhole viaduct and Ash Beds culvert

Method statement

Overview of requirements for flood estimates

Item	Comments
Give an overview which includes: Purpose of study Approx. no. of flood estimates required Peak flows or hydrographs? Range of return periods and locations Approx. time available	This proforma outlines the hydrological calculations carried out for assessment of flood risk for the Proposed Scheme. As part of the scheme, structures may need to be incorporated into the design where a number of watercourses pass beneath the route of the Proposed Scheme. The capacity of these structures needs to be determined to ensure there is no increase to flood risk. It is vital at this stage that the proposed structures are not under designed and hence conservative flows are necessary in line with current requirements of the Proposed Scheme. At a later stage, if a more in-depth assessment determines lower flow, and hence smaller structures would have sufficient capacity, this is acceptable. Country North is a 75km section of the route from north of Lichfield to Banbury. Flows are required where the route crosses all watercourses. This assessment outlines the derivation of flows and hydrographs at two locations for the 1 in 20 (5%) annual probability, 1 in 100 (1%) annual probability, 1 in 100 (1%) annual probability with an allowance for climate change and the 1 in 1000 (0.1%) annual probability.

Overview of catchment

Item	Comments
Brief description of catchment, or reference to section in accompanying report	The two crossings have separate catchments with areas of $2.38 km^2$ and $3.73 km^2$ and are rural in nature.

Source of flood peak data

Was the HiFlows UK dataset used? If so, which version? If not, why not? Record any changes made	Yes – Version 3.1.2, December 2011

Gauging stations (flow or level)

Watercourse	Station name	Gauging authority number	National River Flow Archive number (used in FEH)	Grid reference	Catchment area (km²)	Type (rated/ ultrasonic/ level	Start and end of flow record
Not applicable							

Data available at each flow gauging station

Station name	Start and end of data in HiFlows UK	Update for this study?	Suitable for QMED	Suitable for pooling?	Data quality check needed?	Other comments on station and flow data quality – e.g. information from HiFlows-UK, trends in flood peaks, outliers
Not applicable						
Give link/reference to any further data quality checks carried out						

Rating equations

Station name	Type of rating e.g. theoretical, empirical; degree of extrapolation	Rating review needed	Reasons – e.g. availability of recent flow gaugings, amount of scatter in the rating.
Not applicable			
Give link/reference to any rating reviews carried out			

Other data available and how it has been obtained

Type of data	Data relevant to this study	Data available?	Source of data and licence reference if from Environment Agency	Date obtained	Details
Check flow gaugings (if planned to review ratings)	No				
Historic flood data – give link to historic review if carried out	No				
Flow data for events	No				
Rainfall data for events	No				
Potential evaporation data	No				
Results from previous studies	No				
Other data or information (e.g. groundwater, tides)	No				

Initial choice of approach

Is FEH appropriate? (it may not be for very small, heavily urbanised or complex catchments) If not, describe other methods to be used.	Yes. The bullet points below summarise the general approach to flow estimation for minor watercourses (which SWC-CFA17-001 and SWC-CFA17-004 are classed as): - Define catchment area either on the FEH CD-ROM or using the DTM if catchment area is <0.5km^2; - Check catchment descriptors and adjust where necessary; - Calculate critical duration for the catchment of each crossing using the equation, D (hrs) = Tp*(1+SAAR/1000); and - Calculate flows using the ReFH method from catchment descriptors
Outline the conceptual model, addressing questions such as: Where are the main sites of interest? What is likely to cause flooding at those locations? (peak flows, flood volumes, combinations of peaks, groundwater, snowmelt, tides …) Might those locations flood from runoff generated on part of the catchment only, e.g. downstream of a reservoir? Is there a need to consider temporary debris dams that could collapse?	The main sites of interest are at the crossing locations and hence are the points at which flow has been derived. Each point at which flow has been derived has been named in accordance with the associated watercourse identifier. At this stage it is considered that peak flows are likely to be the main cause of flooding, following development, due to the potentially constricting culvert or bridge structure. As part of this assessment it is not currently deemed necessary to consider the risk of a temporary dam collapse; however, this may be considered in future.
Any unusual catchment features to take into account? e.g. - highly permeable – avoid ReFH if BFIHOST>0.65, consider permeable catchment adjustment for statistical method if SPRHOST<20%; - highly urbanised – avoid standard ReFH if URBEXT1990>0.125; consider FEH Statistical or other alternatives; consider method that can account for differing sewer and topographic catchments; - pumped watercourse – consider lowland catchment version of rainfall-runoff method; major reservoir influence (FARL<0.90) – consider flood routing; - extensive floodplain storage – consider choice of method carefully	The two catchments are within a suitable range of urbanisation and permeability for the ReFH method. All catchments have a FARL >0.9.
Initial choice of method(s) and reasons Will the catchment be split into subcatchments? If so, how?	For this assessment the following level of assessment has been undertaken for these two crossings of minor watercourses: -Calculate flows using the ReFH method from catchment descriptors.
Software to be used (with version numbers)	FEH CD-ROM v3.0[9] WINFAP-FEH v3.0[10]

[9] *FEH CD-ROM v3.0* © NERC (CEH). © Crown copyright. © AA. 2009. All rights reserved.

Locations where flood estimates required

Summary of subject sites

Site code	Watercourse	Site	Easting	Northing	Area on FEH CD-ROM (km^2)	Revised catchment area if altered
SWC-CFA17-004	Un-named non-main river	Route crossing at watercourse identifier shown in the site code column.	436450	266500	2.38	Not altered
SWC-CFA17-001	Un-named drain	Route crossing at watercourse identifier shown in the site code column.	438200	263850	3.73	Not altered
Reasons for choosing above locations		Locations where the route is proposed to cross the respective watercourses.				

Important catchment descriptors at each subject site (incorporating any changes made)

Site code	FARL	PROPWET	BFIHOST	DPLBAR (km)	DPSBAR (m/km)	SAAR (mm)	SPRHOST	URBEXT1990 (updated to 2012)	URBEXT2000 (updated to 2012)
SWC-CFA17-004	1.000	0.30	0.451	1.44	38.2	642	40.83	0.0000	0.0000
SWC-CFA17-001	1.000	0.30	0.336	1.50	33.7	633	47.22	0.0054	0.0021

Checking catchment descriptors

Record how catchment boundary was checked and describe any changes (refer to maps if needed)	The boundary of each catchment has been checked against contours from OS 50K mapping and DTM where available. Adjustment to the catchment boundaries and area was made where necessary.
Record how other catchment descriptors (especially soils) were checked and describe any changes. Include before/after table if necessary.	This proforma outlines the hydrological assessment for the initial stage of assessment. Broad scale checks of catchment descriptors have been carried out. The underlying geology and soils have been reviewed on a broad scale for the larger area of interest and the catchment values for BFIHOST and SPRHOST values appear reasonable, no changes were considered necessary at this stage.
Source of URBEXT	URBEXT1990 (ReFH method)
Method for updating of URBEXT	CPRE formula from FEH Volume 4 on URBEXT1990 / CPRE formula

[10] *WINFAP-FEH v3* © Wallingford HydroSolutions Limited and NERC (CEH) 2009.

Revitalised flood hydrograph (ReFH) method

Parameters for ReFH model

3.2.1 Note: If parameters are estimated from catchment descriptors, they are easily reproducible so it is not essential to enter them in the table.

Site code	Method OPT: Optimisation BR: Baseflow recession fitting CD: Catchment descriptors DT: Data transfer (give details)	Tp (hours) (Time to peak)	Cmax (mm) Maximum storage capacity	BL (hours) Baseflow lag	BR Baseflow recharge
SWC-CFA17-004	CD	2.60	373.86	35.84	1.03
SWC-CFA17-001	CD	2.71	282.66	30.98	0.75
Brief description of any flood event analysis carried out (further details should be given below or in a project report)			None		

Note: only the catchments which are represented on the FEH CD-ROM have been included in the table above.

Design events for ReFH method

Site Code	Urban or rural	Season of design event (summer or winter)	Storm duration (hours)	Storm area for ARF (if not catchment area)
SWC-CFA17-004	Rural	Winter	4.3	ReFH Design Standard
SWC-CFA17-001	Rural	Winter	4.4	ReFH Design Standard
Are the storm durations likely to be changed in the next stage of the study, e.g. by optimisation within a hydraulic model?				

Flood estimates from the ReFH method

Site Code	Flood peak (m^3/s) for the following flood event				Scaling factor ratio of 1 in 1000 (0.1%) flow to the 1 in 100 (1%) flow
	1 in 20 (5%)	1 in 100 (1%)	1 in 100 (1%) climate change*	1 in 1000 (0.1%)	
SWC-CFA17-004	1.45	2.05	2.46	3.64	1.78
SWC-CFA17-001	2.76	3.92	4.70	6.92	1.77

*The 1 in 100 (1%) annual probability flow with an allowance for climate change is the 1 in 100 (1%) annual probability flow factored by 1.2.
** The ReFH flow estimates for these crossings are used to derive scaling factors for the 1 in 1000 (0.1%) annual probability flow in Section 3.3.

Discussion and summary of results

Comparison of results from different methods

3.2.2 This table compares peak flows from various methods with those from the FEH Statistical method at example sites for two key return periods. Blank cells indicate that results for a particular site were not calculated using that method.

Site code	Ratio of peak flow to FEH Statistical peak					
	1 in 2 (50%)			1 in 100 (1%)		
	ReFH	Other method	Other method	ReFH	Other method	Other method
SWC-CFA17-004	1.45			2.05		
SWC-CFA17-001	2.76			3.92		

Final choice method

Choice of method and reasons – include reference to type of study, nature of catchment and type of data available.	Flow estimates calculated using the ReFH method from catchment descriptors extracted from the FEH CD-ROM and adjusted where necessary (i.e. for small catchments <0.5km^2, or where incorrect) have been provided for all crossings and are considered appropriate for the requirements of the study. It is vital at this stage that the proposed structures are not under designed and hence conservative flows are necessary in line with current requirements of the Proposed Scheme. Therefore peak flows from the ReFH method have been used in modelling for all crossings.

Assumptions, limitations and uncertainty

List the main assumptions made (specific to this study).	None listed for these two crossings.
Discuss any particular limitations, e.g. applying methods outside the range of catchment types or return periods for which they were developed.	This stage of the study requires conservative flow estimates for design purposes and therefore the ReFH method peak flow estimate has been used for these catchments.
Give what information you can on uncertainty in the results – e.g. confidence limits for the QMED estimates using FEH 3 12.5 or the factorial standard error from Science Report SC050050 (2008).	There is some uncertainty with the results, however it is considered that the results are conservative and hence would be overestimating, rather than underestimating flows.
Comment on the suitability of the results for future studies, e.g. at nearby locations or for different purposes.	Peak flow estimates have been produced for the purposes of this assessment and should not be used outside of this study except for comparative purposes.
Give any other comments on the study, for example suggestions for additional work.	When the assessment moves to the detailed design phase the FEH Statistical method should be carried out for all suitable catchments for comparative purposes and to provide a greater level of confidence with the results. If there is the opportunity to install temporary flow gauges at the un-gauged crossings, this may also improve confidence in design flows at the detailed design phase.

Checks

Are the results consistent, for example at confluences?	Not applicable separate catchments assessed.
What do the results imply regarding the return periods of floods during the period of record?	Not applicable
What is the 100-year growth factor? Is this realistic? (The guidance suggests a typical range of 2.1 to 4.0)	Not determined.
If 1000-year flows have been derived, what is the range of ratios for 1000-year flow over 100-year flow?	1.77 and 1.78.
What range of specific runoffs (l/s/ha) do the results equate to? Are there any inconsistencies?	Different catchments so not comparable.
How do the results compare with those of other studies? Explain any differences and conclude which results should be preferred.	None.
Are the results compatible with the longer-term flood history?	Not investigated as part of the initial assessment.
Describe any other checks on the results	None.

Final results

Site code	Flood peak (m^3/s) for the following flood event			
	1 in 20 (5%)	**1 in 100 (1%)**	**1 in 100 (1%) climate change**	**1 in 1000 (0.1%)**
SWC-CFA17-004	1.45	2.05	2.46	3.64
SWC-CFA17-001	2.76	3.92	4.70	6.92